SUM-PEAK-COINCIDENCE SPECTROMETER AND GAMMA-GAMMA ANGULAR CORRELATION STUDIES IN Cs^{133}*

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ABSTRACT. A sum-peak-coincidence spectrometer has been set up to study the directional correlation of 356-82 KeV and 276-162 KeV cascades in Cs^{133} following the decay of Ba^{133}. The correlation functions for these cascades have been found out to be :—

$W(\theta) = 1+(0.0350\pm0.0015)P_2(\cos\theta)-(0.0048\pm0.0034)P_4(\cos\theta)$ and $W(\theta)=1-(0.412\pm0.018)P_2(\cos\theta)-(0.025\pm0.015)P_4(\cos\theta)$ respectively. These results support spin assignments $1/2^+$ for 438 KeV level and $5/2^+$ for 162 KeV level in Cs^{133}. The mixing ratios for 82 KeV and 162 KeV transitions come out to be $(97.2\pm0.3)\%$ M1$+(2.8\pm0.3)\%E_2$ and $(75.8\pm3.2)\%+(24.2\pm3.2)\%$ E_2 respectively.

INTRODUCTION

An ordinary slow-fast coincidence spectrometer is suitable for the study of angular correlation for those cascades which are well resolved and have moderately high intensities. In case the competing cascades deexciting the same level are close in energy, the slow-fast coincidence spectrometer fails to yield very accurate results and especially in those cases where the asymmetry is relatively small it rather becomes impossible to draw any unambiguous conclusions regarding the spin assignments to the levels involved. Further even when the measurements on such cascades is attempted by gating at the lower or the higher energy ends of the constituents peaks, it puts a stringent requirement of high degree of electronic stability on the spectrometer which is generally hard to achieve. In case of relatively weak cascades slow-fast-coincidence spectrometer requires a lot of time to make any worthwhile angular correlation measurements.

Sum-peak coincidence spectrometer of Kantele *et al*, (1962) possesses some special advantages over the ordinary slow-fast coincidence spectrometer which makes it more suitable for carrying out gamma-gamma angular correlation measurements in the above mentioned cases. These advantages are (a) double coincidence detection efficiency (b) a lack of narrow gating channels (c) insensitivity to minor electronic drifts. Further in some cases where the sum peaks are well

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separated the angular correlation for various cascades can be studied simultaneously with the help of a sum-peak-coincidence spectrometer incorporating multichannel analysor.

With these advantages in view a sum-peak coincidence spectrometer has been set up for angular correlation measurements. Its behaviour has been checked with a standard cascade of Ni^{60} and gamma-gamma angular correlation measurements have been carried out for 356-82 KeV and 276-162 KeV cascades in Cs^{133}.

EXPERIMENTAL ARRANGMENTS

A schematic diagram of the sum-seak-coincidence spectrometer is shown in figure 1. The two detectors (SH) are a matched pair of 2″ dia × 2″thick NaI(TI)

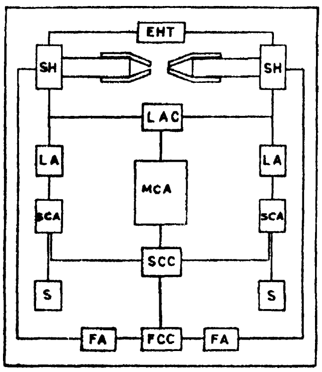

Fig. 1. Block diagram of experimental set-up.

crystals mounted on RCA 6292 photomultipliers. The effective resolving time of the set up was checked to be 65 n-secs. Two single channel analysers (SCA), operated in integral-bias mode, delivered output pulses of constant amplitude which along with the output pulses of the fast coincidence circuit (FCC) operated a slow coincidence circuit (SCC). The output of the slow coincidence circuit gated a RCL 256 channel analysor. The linear adding circuit (LAC) received pulses from the two scintillation heads, the gains for which were set almost equal. Final equalization of the gain was achieved by adjusting a potentiometer in the linear adding circuit itself. The output of the adder was fed to the multichannel analyser. Compton graded lead cylinders and lead cones were used to minimize the crystal to crystal scattering.

MEASUREMENTS AND RESULTS

All the measurements were carried out at a source to crystal distance of 10 cm. The radioactive source Ba^{133} in the form of $BaCl_2$ dissolved in HCl was obtained from Bhabha Atomic Research Centre, Bombay, India. A small source was prepared in a perspex holder of cylindrical shape with a small hole at the top.

The diameter of the hole was 2 mm. and the depth was about 6 mm.; the wall thickness was 2 mm. The source could be centered within 0.5% accuracy. The coincidences were recorded at seven angles, at an interval of 15° each, between 90° and 180°. Integral counts of the movable arm were recorded at all the angles to correct for any decentering of the source. After making a least square fit of the correlation data (Rose, 1953) the correlation coefficients were corrected for finite angular resolution of the detectors (Yates, 1964).

The whole set up was checked for angular correlation measurements with the standard cascade (1.33—1.17 MeV) of Ni^{60}. To check the insensitivity of the whole set up to minor electronic drifts the integral biases were varied a little on both sides from the original setting. It was observed that the area under the sum peak is not affected at all. An inequalization at the adder made the sum-peak broader but its area as a whole did not change. The coincidence rate with this spectrometer was found to be almost double of that with a simple slow-fast coincidence set up.

356-82 KeV CASCADE IN Cs^{133}

The decay scheme of Ba^{133} as given by Yin *et al*, (1964) is shown in figure 2. Gamma-gamma angular correlation measurements for 356-82 KeV cascade in Cs^{133} have been carried out by sum-peak coincidence method. The integral biases in the two channels were set at 70 KeV so as to bias out Cs^{133} KX ray and 54 KeV gamma ray.

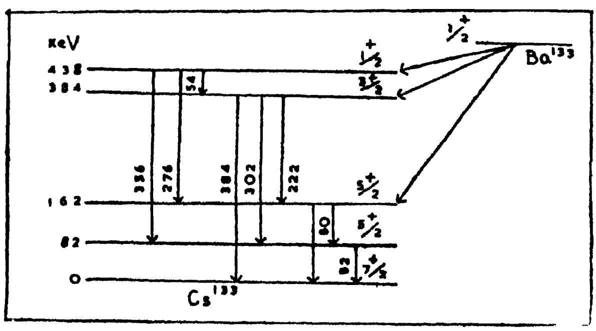

Fig. 2. Decay scheme of Ba^{133}.

Figure 3. (solid curve) shows the observed sum-peak coincidence spectrum with 70 KeV bias. Sum-peaks at 162 KeV, 384 KeV and 438 KeV are observed corresponding to the summing of 80-82 KeV, 302-82 KeV, 356-82 KeV and 276-162 KeV cascades. The 438 KeV sum-peak contains contributions due to two cascades namely 356-82 KeV and 276-162 KeV. The contribution due to the latter cascade was measured and subtracted at each angle separately (measurements discussed in next section). To avoid any contribution from the sum of 302-82

KeV gamma rays, falling in the lower portion of the sum-peak at 438 KeV, only the upper half of the area of 438 KeV peak was taken. This way about 1.6×10^5

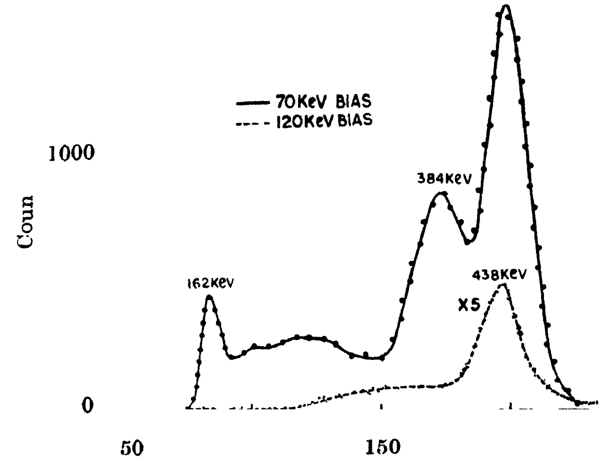

Fig. 3. Sum-peak-coincidence spectra of Ba^{133} with a pair of 2″×2″ NaI(Tl) detectors and source-to-crystal distance of 10 cm. Solid line and dotted line show the 70 KeV bias and 120 KeV bias spectra respectively.

coincidence counts were collected at each angle. After applying finite solid angle correction the coefficients A_2 and A_4 for 356-82 KeV cascade are given in table 1 along with the results of other authors. Figure 4 (solid curve) shows the observed angular correlation function $W(\theta)$ for the 356-82 KeV cascade.

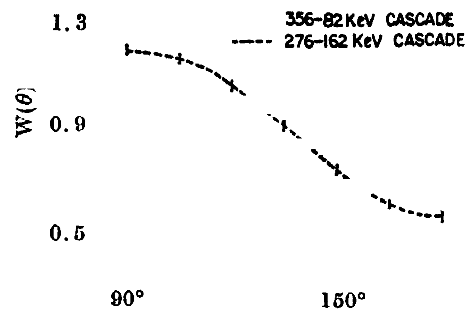

Fig. 4. Plots of $W(\theta)$ vs θ for the cascades 356-82 KeV and 276-162 KeV respectively.

The spin of the ground state of Cs^{133} and Ba^{133} have been measured (Mack *et al*, 1950 and Goldhaber *et al*, 1952) to be $7/2^+$ and $1/2^+$ respectively. The electron capture transition from the ground state of Ba^{133} to the 438 KeV level of Cs^{133} being of allowed type the spins $1/2^+$ and $3/2^+$ are possible for the 438 KeV level.

A spin of $3/2^+$ has been proposed (Subba Rao, 1961) on the basis of 81K-356γ electron gamma directional correlation measurements. Other authors (Bodenstedt *et al*, 1959; Münnich *et al.*, 1963; Arya, 1961 and Yin *et al*, 1964) assign a spin $1/2^+$ on the basis of 356-82 KeV gamma-gamma angular correlation measurements. The assignment $3/2^+$ to the 438 KeV level is rejected as this level is not reached in the coulomb excitation of Cs^{133} (Fagga, 1958). Our results confirm $1/2^+$ assignment to the 438 KeV level. Assignment of $3/2^+$ requires A_4 to be positive while experimentally it is found to be negative. Recent measurements (Thun *et al*, 1966 and Othaz, 1965) onthe directional correlation of 81K-356γ KeV electron gamma correlation also support $1/2^+$ spin assignment to 438 KeV level. Thus the spin sequence for the 356-82 KeV cascade is :
$\frac{1}{2}(Q)\ \frac{5}{2}\ (D, Q)\ \frac{7}{2}$

Figure 5 shows a graphical analysis of the results for 356-82 KeV cascade in terms of above spin sequence for determining the quadrupole admixture in the 82

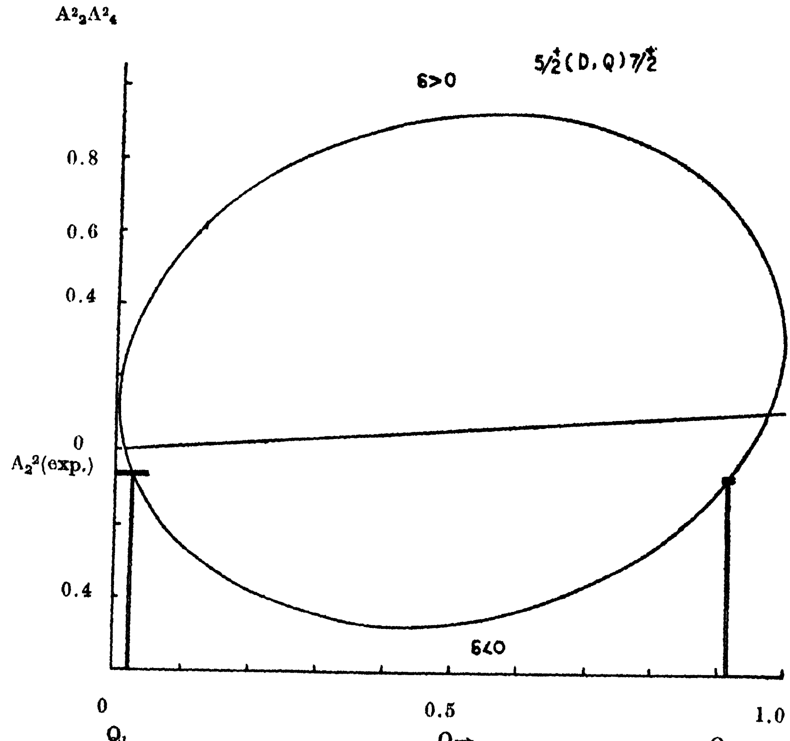

Fig. 5. Quadrupole admixture for the 82 KeV transition ($5/2^+ \rightarrow 7/2^+$).

KeV transition using the single transition mixture curve (Arns and Wiedenbeck, 1958). A quadrupole content of $Q_1 = 0.028 \pm 0.003$ is given for the 82 KeV gamma ray. The value Q_2 is incompatible with the positive value of $A_4^{(2)}$ (expt). Thus it is concluded that the mixing ratio of 82 KeV gamma ray is $2.8 \pm 0.3\%$ E_2 and $97.2 \pm 0.3\% M_1$. This result is in agreement with the recent value obtained by Thun *et al* (1966) (Viz $\delta = -0.155 \pm 0.003$ giving $E_2 = 2.34 \pm 0.08$ %) on the basis of 81K—356γ KeV angular correlation.

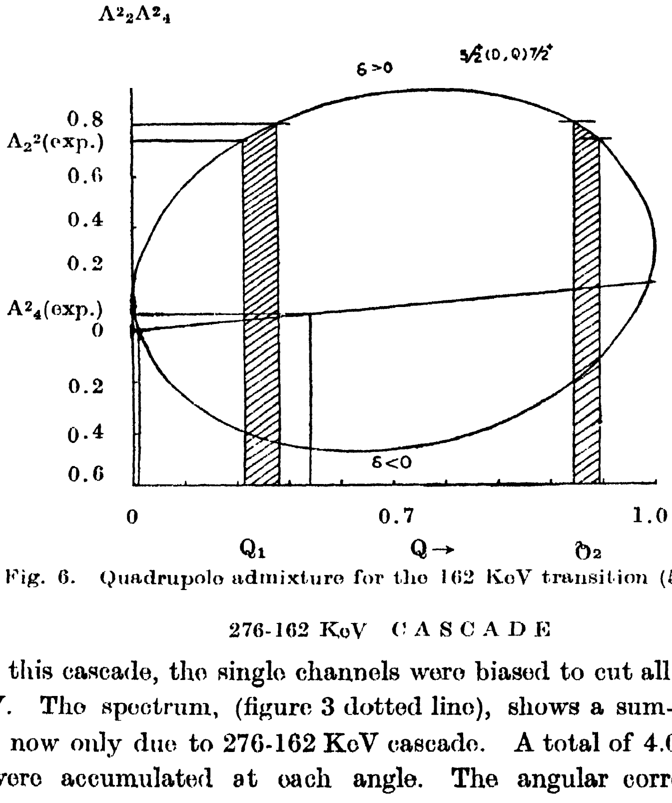

Fig. 6. Quadrupole admixture for the 162 KeV transition ($5/2^+ \to 7/2^+$)

276-162 KeV CASCADE

For this cascade, the single channels were biased to cut all gamma rays upto 120 KeV. The spectrum, (figure 3 dotted line), shows a sum-peak at 438 KeV which is now only due to 276-162 KeV cascade. A total of 4.0×10^4 true coincidences were accumulated at each angle. The angular correlation coefficients after finite solid angle correction along with the results of other workers are given in table Figure 4 (dotted curve) shows the angular correlation function $W(\theta)$ for the 276-162 KeV cascade.

Since the spin of 438 KeV level has been confirmed to be $1/2^+$ and the ground state spin being $7/2^+$, the results for the 276-162 KeV cascade require a spin $5/2^+$ for the intermediate 162 KeV level. The other possible assignment of $3/2^+$ is eliminated as it requires A_4 to be zero and experimentally it is found to be non-zero. Therefore the spin sequence for 276-162 KeV cascade is :

$$1/2(Q)\ 5/2(D,Q)7/2.$$

Figure 6 shows a graphical analysis of the results for the 276-162 KeV cascade in terms of the above spin sequence for the second transition to be mixed. The two possible solutions on the basis of $A_2^{(2)}$ (expt). are :

$$Q_1 = 0.240 \pm 0.32$$
$$Q_2 = 0.857 \pm 0.027$$

The experimental value of $A_4^{(2)}$ restricts Q within the limits $0.09 \leqslant Q \leqslant 0.35$; so the value Q_2 is rejected. Therefore the mixing ratio of the 162 KeV gamma ray is 24.2±3.2% E_2 and 75.8±3.2% M_1. These results are in agreement with the results of Aggarwal *et al*, (1965) Münnich *et al*, (1963) and Thun *et al*, (1966) but not in agreement with the results for Yin and Wiedenbeck, (1964).

Table 1

Gamma-gamma directional correlation measurement results on 356-82 KeV 276-162 KeV cascades in Cs^{133}

356-82 KeV cascade

Authors	A_2	A_4	Assignments
Subba Rao (1961)	0.046±0.011	−0.008±0.014	$3/2^+(M_1+E_2)5/2^+(M_1+E_2)7/2^+$ $Q_{82}=0.004$
Bodenstedt, *et al*, (1959)	0.042±0.005	−0.004±0.007	$1/2^+(E_2)\ 5/2^+(M_1+E_2)7/2^+$ $Q_{82}=0.025$
Münnich *et al*, (1963)	0.0379±0.0020	−0.0031±0.0015	$1/2^+(E_2)5/2^+(M_1+E_2)7/2^+$ $Q_{82}=0.0236\pm0.0010$
Arya, (1961)	0.042±0.0050	−0.0041±0.0038	$1/2^+(E_2)5/2^+(M_1+E_2)7/2^+$ $Q_{82}=0.035\pm0.005$
Yin *et al*, (1964)	0.0331±0.0017	0.0045±0.0033	$1/2^+(E_2)5/2^+(M_1+E_2)7/2^+$ $Q_{82}=0.024\pm0.001$
Thun *et al* (1965)	0.037±0.005	−0.002±0.006	$1/2^+E_2)5/2^+(M_1+E_2)7/2^+$ $Q_{82}=0.023\pm0.006$
Present work	0.0350±0.0015	−0.0048±0.0034	$1/2^+(E_2)5/2^+(M_1+E_2)7/2^+$ $Q_{82}=0.028\pm0.003$

276-162 KeV Cascade

Bodenstedt *et al*, (1959)	−0.442±0.009	−0.040±0.012	$1/2^+(E_2)5/2^+(M_1+E_2)7/2^+$ $Q_{162}=0.31$ or 0.83
Munnich *et al*, (1963)	−0.421±0.015	−0.016±0.013	$1/2^+(E_2)5/2^+(M_1+E_2)7/2^+$ $Q_{162}=0.26\pm0.03$
Yin *et al*, (1964)	−0.328±0.009	−0.067±0.01	$1/2^+(E_2)5/2^+(M_1+E_2)7/2^+$ $Q_{162}=0.951\pm0.006$
Aggarwal *et al*, (1965)	−0.442±0.011	−0.026±0.014	$1/2^+(E_2)5/2^+(M_1+E_2)7/2^+$ $Q_{162}=0.32\pm0.03$
Present work	−0.412±0.018	−0.025±0.015	$1/2^+(E_2)5/2^+(M_1+E_2)7/2^+$ $Q_{162}=0.24\pm0.03$

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